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VIRTUAL REALITY

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This paper reviews the exciting field of virtual reality. The author describes the basic concepts of virtual reality and finds that its numerous potential benefits to society could revolutionize everyday life. The various components that make up a virtual reality system are described in detail and a discussion of the state of the art is presented. The author concludes that although the U.S. dominates the field, the Japanese now spend ten times more on research and are closing the gap. A recommendation is made to incentivize research in this area and to proceed with the national information network.

DISCLAIMER

INTRODUCTION

Imagine yourself as a member of an engineering design team in St. Louis. Your team has been working on a new, improved artificial heart that shows great promise for ultra reliability and longevity. The latest changes have been made, incorporating the feedback from your collaborating heart surgeon to make the device easier to install. As the team sits in its design room, passing the artificial heart around, one member asks to review the specifications on the valves from the supplier in Los Angeles. You call him on the phone and moments later he walks into the room and answers the question. Satisfied with your team's latest efforts, you tell the surgeon in New York that you are ready for a test. Your team walks into his laboratory, carrying the heart, and hand it to him. The surgeon places the heart on a tray beside an operating table on which is laying a cadaver. Some of your team still has trouble being squeamish as he slices open the cadaver, removes the old heart, and quickly and easily installs the artificial one. With a wink and a smile, he gives you a thumbs up. Success at last! Now, suppose that this entire sequence of events took place - including most of the design process to create the heart - without any of the participants leaving their own personal residences. There was no real artificial heart and no real cadaver. Everything, including the wink and smile, was a computer simulation. Sound far fetched? Maybe, but this kind of technology has already been

demonstrated.[1] [2] It is called virtual reality and its potential impact on our everyday lives will far exceed the telephone and television - combined. As Vice President (then Senator) Gore has said, "Virtual reality promises to revolutionize the way we use computers... It has the potential to change our lives in dozens of ways."[3]

In this paper, I will examine virtual reality by first describing what it is, how it started, and what it consists of. Then, I will discuss the benefits of virtual reality and why it is so powerful, followed by some current and potential uses of the technology in different walks of life. Next, I will talk about what it takes to implement a virtual reality system and what the state of the art is in doing so. Finally, I will briefly talk about who is involved in this research and close with some recommendations.

WHAT IS VIRTUAL REALITY?

The first question to ask in examining this new technology is just what is virtual reality. Steve Tice is the president of a firm that is doing a leading edge business in the field, Sim Graphics Engineering Corporation. He defines virtual reality (VR) as "an environment that provides realistic clues to some or all senses sufficient to engineer in the user a willing suspension of disbelief."[4] In more layman's terms - a pretend world where you can do things that seem real. This pretend world is generally computer-based. How you create, use, access and

benefit from this world is what we will discuss throughout this paper.

History

Though vir'ual reality seems to be a new technology, the term and the field of research was coined by Ivan Sutherland, an icon in the field of computer graphics, in 1965. Before most people even knew what a computer was, he demonstrated a nelmet-mounted display at the University of Utah in 1968.[5] As such, this infant field has really been under research for 28 years. It is an American-invented technology - one in which we had exclusive involvement in until the past 3-4 years.[6] The more recent growth in computing and display technologies has really spurred the growth in virtual reality research as well. Media attention, including such things as the movies Total Recall and Lawnmower Man, have similarly fueled the public interest - which, in a round about way, has helped encourage investment in and advancing of the research.

What does a virtual reality system consist of?

In trying to answer this question you have to refer back to the definition of virtual reality. The definition talks about "...an environment that provides realistic clues to some or all senses sufficient to..." Thus, the definition defines a spectrum of sophistication that changes based on what the VR system is to be used for. The system itself is usually broken down into three

parts:

- an environment,
- a method to provide clues to the user's senses, normally limited to sight, sound, and touch, and
- a method to link environments together.[7]

Environment. The environment normally consists of computer software programmed to include a three-dimensional representation of what is to be simulated. The programming includes as much detail as necessary about the contents of the environment to provide sufficiently realistic clues to the user.

Access. The user accesses this environment through some type of visual display - typically a helmet-mounted visual display that includes three-dimensional sight and sound. To enhance realism, some form and level of haptic interface is necessary. Haptic is a term that goes far beyond the simple sense of touch. It refers to your ability to do such things as tell the softness of your chair and the type of fabric in your pants as you sit down. It is your ability to tell that a door has opened by the draft on the back of your neck. Basically, it is the awareness you have of your environment based on your total body senses - more than just reaching out and touching something. For total realism, the VR environment would have to be accessed through a total haptic interface.[8] Luckily, this is not usually required to meet the "sufficient" part of the virtual reality definition. Normally, it is adequate to provide some sort of

simpler touch feedback - through a glove (or perhaps body suit) - and some mobility for the user (for realism purposes) - through a treadmill, wire suspension, water tank, or limited walk-around area. Additionally, a tracking device is required to place the user accurately in the VR environment so that the visual displays reflect and are corrected for the user's motion.

Linking environments. For more than one person to have access to the environment at the same time, or for geographically separated environments or people, a method is needed to link them together. This is accomplished through a computer network just as office computers are. However, in the case of virtual reality, this network must be capable of handling large amounts of data at very high speeds.

Putting it all together. To tie this altogether, picture a person standing in a room. He looks like someone from the movie The Fly because he has on a helmet with individual displays for each eye. On each hand he has an electronic glove. On the ceiling is an electronic tracking device and in the corner is a computer. What the wearer of the helmet sees is a subway terminal in Berlin and he is free to walk around the terminal, interact with it, and make changes to its design.[9] This is virtual reality.

THE BENEFITS OF VIRTUAL REALITY

Now that you hopefully have some idea of what virtual

reality is, you might be saying - so what. It's just another Nintendo system that will benefit the Nintendo stock holders, but certainly won't benefit our society as a whole. By analogy, I might counter by saying that Alexander Graham Bell suffered from similar public doubt. Instead, let me explain a little more rigorously why the concept of VR is important, then go through some practical examples of its use.

What does virtual reality do for us?

Remember that virtual reality allows the user to experience the environment, interacting with it through our hands, our eyes, and our ears. Studies at Northwestern University have shown that our minds can process information much better when it is presented as sights, sounds, and touch as opposed to just numbers and letters on a page. Additionally, their studies showed that people learn much more through their experiences than they do by memorizing rules.[10] One reason for this is described in a article by Gene Bylinsky where he quotes Larry Smarr, the Director of the National Center for Supercomputing Applications at the University of Illinois. He says that VR is so powerful in helping people interact with computers because "...the eye-brain system is incredibly advanced. Looking at the world, we absorb the equivalent of a billion bits of information per second, as much as the text in 1,000 copies of Fortune. But, our mental text computer is limited by the fact that we can read only about 100 bits - or characters - per second." Additionally, half of

the brain is devoted to visual processing, resulting in visual representations being the most efficient way to understand and manipulate data.[11] So then, I think it is plain to see how a VR system can provide great efficiencies in our ability to learn, do, or create.

The benefits from the virtual reality interface between man and computers has spawned a new phrase called "Intellige-Amplifying" (IA) system. In a testimony before a Senate Subcommittee on Science, Technology and Space, virtual reality was seen as a major innovator or productivity enhancer. Its ability to couple computers and humans together to enhance problem solving, allows the handling of much more difficult and complex problems than is possible with artificial intelligence (AI). Virtual reality was seen as "crucially important for the research and development competitiveness of American scientists and engineers."[12] With this background behind us, lets go through some examples, based on current research, of how we can benefit from virtual reality.

Manufacturing/business

The whole crux of competition in today's global marketplace is in the ability to shorten the cycle time from concept to delivery of the product, while factoring in the customer's desires. This is precisely what VR technology will allow you to do. By using realistic simulations of the product, the manufacturer will be able to greatly shorten his development time

by being able to avoid the need for prototypes.[13] By using "experiential prototyping," the designer can actually experience what he is building - understanding how to fix mistakes and make a better design.[14] By sharing this experience with his customer, he can ensure requirements are met.[15] The cycle time can also be reduced because not only can engineering be done concurrently, but training can also be done concurrently. The people who will do the actual manufacturing can be trained, the people who will use the product can be trained, and the people who may need to maintain the product can be trained - all concurrently in a virtual environment - with their inputs being fed back into the design.[16]

As an example, the University of Washington has a contract with the Boeing Corporation to develop a "virtual protospace." This is a place where you go to design airplanes - to include all the steps, through testing them in a virtual wind tunnel and flying them.[17] They currently are developing a virtual walk-through model of the new Boeing 777.[18] Additionally, Boeing has a virtual model of a tilt-wing rotor aircraft that you can "walk" out to, open hatches and examine gauges, and get in and fly. After flying, you can land it, walk around to the rear cargo door, and go in and change the seating configuration to suit your needs.[19]

In Japan, a customer can walk into a department store today, don a VR helmet and glove, and proceed to design his own kitchen.

The customer can walk around inside the virtual kitchen, open and close drawers, turn on the water, etc. Once the customer is satisfied, the plans are produced and the kitchen is made to order.[20] The Japanese are further developing this system to include various aspects of lighting, noises, humidity, and drafts.[21]

Education

The whole field of education and training will significantly benefit from applying virtual reality to the classroom. By actually experiencing the laws of physics and being able to interact with historical figures, children's and adult's ability to grasp complex ideas will be greatly stretched - making learning easier and longer lasting.[22]

Exploration and defense

The trend has been to try to remove humans from dangerous situations through robotics or remotely - piloted vehicles. The problem with this concept is that the flexibility and adaptability of the device is limited as compared to actually having a human operating it directly. Now, through a combination of telepresence (transporting yourself electronically to the environment of the device) and virtual reality, a person can operate the device remotely with the same effectiveness as if he was there. The Japanese have also demonstrated this technology by remotely controlling a robot by making it appear that the

operator is the robot in the virtual world.[23]

Leisure activities

Numerous examples exist of the current use of virtual reality for leisure activities. Most are still crude, but some, such as Disney World's Space Ride, are very realistic. The use of VR for leisure activities is sure to explode in the not too distant future, with a person being able to do or experience almost anything - probably from the comfort of his own home.

Impact on quality of life

With goods and services produced more efficiently and education and training more effective, our quality of life must certainly improve. By being able to travel to your virtual workplace over a network - in essence being able to conduct much of your business from home - our society may be able to solve other problems. For example, there may be less need for highways, cars, mass transit, and energy to heat office buildings. These changes will result in an associated reduction in pollution and a positive effect on our environment. With people at home more often, there will be less need for child care and perhaps an increase in family unity and parental responsibility, resulting in all the positive effects these changes bring. On the downside, there is a possibility that virtual reality could be so realistic that it becomes the narcotic of the 21st century, with people preferring the virtual

experience to the troubles of everyday life. Whether any of this becomes more than just another fancy arcade game depends on the development of the technology and the investment of business. Lets look now at where we are.

WHAT IS THE STATE OF VIRTUAL REALITY TECHNOLOGY?

So far, in this paper, I've discussed what virtual reality is and what constitutes a VR system. Also, I've elaborated on the uses and benefits of virtual reality to the point at which I hope you are excited about the possibilities. But your question now should be whether this is just another H.G. Wells story or will it come true as some of his predictions did. Let's look now at where the technology actually is.

Environment

As we have discussed, the VR environment is really its heart - consisting of the software to create it and the hardware to make it live.

Visual software. A major issue on the software side is the creation of the visual aspect of the environment. This is currently done as it is in computer-aided design systems through the creation of polygons. These polygons are then given various attributes that allow them to take on the characteristics of solids, for example, with the associated weights, material properties, etc. Once an item is constructed it is normally

added to a library of objects (or elements that build objects) much like various kinds of construction material is used to build a house. The library is then used to construct different VR environments.[24] To construct an entire world, of course, is time intensive, but with the use of libraries the task is doable.

People software. Currently, most VR systems represent "people" as cartoon-like. Depending on the usage, this may be adequate. However, higher level uses of virtual reality, like some of those discussed, require much more sophistication in the representation of people than a cartoon. The perceived subtleties of human communication - facial expression, body language, and appropriate emotional responses to stimulus - have tremendous impact in our interaction with others. Research is ongoing in this particular area to develop software libraries that contain computer entities (people) that are programmed with personalities. These objects are able to respond to body language and other forms of communication in appropriate manners.[25] Additional work is being done in such areas as the mechanics of collaborative design to determine the psychological and social aspects of how people accomplish this task in the real world. This will help researchers understand the kind of information, systems and implementation needed to model the real world in the virtual world.[26]

Sound software. Another obviously important area for a realistic environment is sound. Significant in-roads are being

made in the modeling of sound to give it its three-dimensional nature of coming from the right place at the right time. This is one of the keys to realistic simulations that has uses far beyond aesthetics. For engineering applications and electronic prototyping, realistic sound modeling will allow testing of the effects of acoustics and associated stresses as changes in the environment are made.[27]

Software configuration control. Modeling all these aspects of the real world results in a tremendous challenge for software configuration control and interface standards as individual companies design and build tool kits and libraries to be used to construct virtual worlds.[28]

Hardware requirements and lag. All of this software requires significant processing power to run. So we now turn our discussion to the computer hardware requirements for a virtual reality system. There is one measure that defines the minimum processing power and that is the system lag. Lag is essentially the time it takes from an input to result in a response. For example, if you take a step or turn a wheel, does your foot move instantly or does the wheel turn instantly (zero lag) or do they move a tenth of a second after they should have (100 millisecond lag). The human brain's threshold to detect lag is about 10 milliseconds, so for a realistic virtual environment, the desired system response is less than this amount. The higher the lag the less realistic (and less useful) the VR system would be, up to

the point of being counterproductive or providing negative training. A 300 millisecond system lag, for example, would even cause motion sickness.[29]

Visual drives lag. The thing that slows computers down most of all, having the biggest drain on processing power, is the generation of the visual environment - the polygons that the virtual world is built from. The more polygons used, the more realistic the visual environment will be. On the other hand, the more polygons used, the greater the system lag (if the processor is constant). The result is a trade off between a realistic scene and realistic motion.

How many polygons? It is estimated to take the ability to display approximately 100 million polygons per second (pps) per eye to simulate the real world. Current technology is able to generate from 60,000 to 200,000 pps per eye, with texture, or about 1 million pps per eye without texture.[30] This can be displayed at a lag of 60-70 milliseconds, which gives a usable and reasonably realistic scene. To get below the 10 millisecond threshold with the similar level of realism will take a processor capable of about 90 million instructions per second (mip). This should be achievable in a couple years, while the capability to display a "no lag" totally realistic display is estimated to take 10-20 years.[31]

Access to the virtual environment

Creating the best virtual world possible does no good if it can't be accessed by humans. This access has to be done just as it is in everyday life. That is, through our senses.

Visual access. The most important of the senses to virtual reality is vision. The visual images provided to the eyes by a VR system must mimic reality as closely as possible. They, therefore, must be high resolution, portray a three-dimensional image, and have the normal field of view of the moving eye.[32] This is typically provided by a helmet-mounted visual display that positions liquid crystal displays (LCDs) in front of each eye. Optically speaking, this gives good resolution. But, in comparison to the eye that has 15 million light receptors and 1 million optic fiber nerves, LCDs only result in about 1/50th the detail that the eye is capable of. Further advances in technology should push this down to about 1/15th in a couple years.[33]

An approach different than liquid crystal displays is being researched by the University of Washington. Called a "virtual retinal scanner," this approach to providing the visual interface to virtual reality uses a phased array of lasers to scan the image directly onto each eye's retina. The 4000 by 4000 line picture element that is scanned results in what's termed a "Maxwellian view" where the perception of a wide field of view image with extremely high resolution is created. In this method,

the impression is not one of looking at a picture, but actually "seeing" the virtual world. Other significant advantages of this method over liquid crystal displays appear to be size, weight, and cost. The scanners should be able to be made very small, weighing less than an ounce each, and at a cost of around $500-$600 for each eyepiece. The laser light used is one of very low power - described to be "equal to the light from the sun reflected off a tree."[34]

Tracking. To ensure the visual scene correlates with head, eye and body movements, a VR system has to provide a method of tracking the head in space. This is typically done through electromagnetic sensors. To provide a good display, this tracking needs to be accurate within one millimeter in translation and within a fraction of degree in rotation. Current technology allows tracking to be accomplished within a 4-5 foot radius, soon to be 20 feet. The biggest problem, though, is lag. This lag has the same effect as previously discussed. Presently, tracking lag is relatively high at 100-200 milliseconds. However, with better engineering it is expected that it can be reduced to the 20 to 40 millisecond range soon. Other efforts in this area include work on a portable unit for working outdoors and research on using a global positioning system-type method to help establish the user's position.[35]

Sound access. In addition to visual displays and tracking systems, a helmet display also provides access to the virtual

world by sound. From a hardware point of view, this is nothing sophisticated. The realism comes from the software modeling of the sound, as previously discussed. Properly implemented, the three-dimensional sound input can provide for as realistic an experience as the visual input can.[36]

Touch access. To experience the virtual world as if you were really there, you have to be able to touch it. This, perhaps, is the most difficult area to implement. There are two facets to modeling the sense of touch in a VR system. One is the accurate tracking and positioning of the various parts of the body. The other and much more difficult is the feedback to the body of the correct "feel." Most research in the first area is involved with the hand. Generally, a glove is made that has fiber optic cables running the length of the arm, hand, and fingers. Light is shown through the fiber optics and as the hand is bent the amount of light transmitted changes. This is read and analyzed by a computer to correctly position the hand in the virtual world.[37] This same approach (though engineering-wise is more complicated) is used to make an entire body suit. In this manner, all the body positions can be accurately positioned.[38]

The feedback of feel to the virtual traveler runs the gamut from force feedback to texture and haptics to kinesiology (the science of senses that tell you you're moving).[39] Most work on force feedback requires the user to grab something in the real world that provides the appropriate resistance (a joystick or a

scalpel for example). Software modeling of the appropriate tactile and haptic clues has been reasonably successful. Researchers at MIT have been able to model such abstract things as the feeling of stirring a bucket of ice cubes combined with molasses. Similarly, the sensation of feeling the texture of sandpaper is being studied - implemented through many pressure pins in the wearer's glove or bodysuit.[40] [41] Giving the virtual traveler mobility in the virtual world is either done by just walking in the real world, treadmills, trapeze setups, or in water tanks - which can provide such capabilities as flight to the traveler.

To be able to really provide the realistic touch/motion interface with the virtual world will probably require a whole new technology or discovery. For example, research is being done on direct brain to computer connections that could provide the correct nerve stimulus for the simulation desired - much like the way you realistically feel things in your dreams.[42] One segment of this research involves a thought transducer, where thoughts or brain activity is measured and then used to control something (through an electronic controller). This particular experiment has been successful when the participants learned to control their brain activity. As in other methods, a major problem to solve is one of lag. In this case lag results from the excessive filtering required to get the low voltage brain waves separated from other noise.[43]

Linking the environments

The ability to communicate with people or other virtual environments that are physically separated requires a network. Existing telephone lines are normally not adequate to carry the high volumes of data required of a typical VR system. Virtual reality needs a fiber optic network to function smoothly at its realistic level of detail. The good news is that the current government administration is pushing hard for a national information infrastructure - whose backbone is a fiber optic system - as the interstate highway system of the information age and the 21st century. This gigabit system is projected to cost over $300 billion and should be completed by 2015.[44] In the interim, and as VR is growing, experts view the Integrated Services Digital Network (ISDN) and advances in data compression technology as methods to provide some usable product over the existing telephone lines.[45]

Who is the leader in VR research and application?

So, who is providing all the research and breakthroughs in virtual reality technology? Well the good news is that this exciting and revolutionary technology is still being led by the U.S. The bad news is that even though we are the world experts in this field, only a relatively small number of groups or companies are working on it. In fact the number is embarrassingly pitiful. There are currently six leading commercial firms in the U.S. with a total of 92 employees working

in this field. These firms do work with other major firms to help develop VR for their needs (Boeing and Caterpillar for example) and, as such, leverage their small size to an effectively bigger one.[46] In addition, there are several universities - most notably the University of North Carolina, the University of Washington, and MIT - doing significant research. By comparison, the Japanese - who just started in the field 3-4 years ago - are now spending at least 10 times as much as the U.S. on virtual reality research.[47] In addition, Japan's Ministry of International Trade and Industry (MITI) has set up a commission on artificial reality to establish a coordinated government-industry approach to developing the technology.[48] As with other technologies in the past, the Japanese have been aggressive in employing U.S. consultants in virtual reality to help with their own development.

RECOMMENDATIONS AND SUMMARY

The exciting field of virtual reality has the potential to change our lives in many ways. Even though the concept has been around since 1965, the relatively-recent exponential growth in computer and microelectronics technology has caused virtual reality research to blossom. Though still about 20 years away from making the world of science fiction a reality - usable VR products should be available to the home in 5 years. For this technology to provide real benefits to society and not just be another arcade game requires two things. The first is the

establishment of the national information infrastructure to provide a means of carrying the kinds of data we will need in the information age. The second is a coordinated research and development approach, championed at the national level and incentivized by government, to ensure we maintain a lead in fielding this technology. If these two steps are taken, the benefits of virtual reality to nearly every walk of life will only be limited by our imagination.

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